WYOMING GAME AND FISH DEPARTMENT

FISH DIVISION

ADMINISTRATIVE REPORT

Title: Marquette Creek, Tributary to South Fork Shoshone River, Instream Flow Studies

Project: AW-CY-IF4-511

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EXECUTIVE SUMMARY

A 0.5-mile segment of Marquette Creek in the South Fork Shoshone River basin was selected for an instream flow water right because the drainage has high purity Yellowstone cutthroat trout (YSC). This report provides flow recommendations developed from studies conducted in 2004. Riffle hydraulic characteristics under the Habitat Retention approach were examined to develop monthly flow recommendations that maintain fish movement and invertebrate production. The flow levels from Habitat Retention will maintain summer adult trout habitat according to the Habitat Quality Index (HQI) model. During winter months, October through April, the recommendations will maintain natural winter flow levels and trout survival. The flow recommendations do not address maintenance of channel geomorphology and long-term habitat; but flow calculations for maintenance of channel geomorphology are presented in Appendix 1.

Important YSC habitat on public land will be directly protected if the instream flow segment and recommendations identified in this report advance to permit status. In addition to the 0.5-mile segment, over 3.8 headwater stream miles will be indirectly protected. A recommended flow of 1.1 cfs is recommended for each month of the year (Table 1). Additional channel maintenance flow recommendations for long-term habitat maintenance are presented in Appendix 1.

Table 1. Instream flow recommendations to maintain trout habitat in the Marquette Creek instream flow segment.

Monthly Flow Recommendations (cfs)											
Oct	Nov	Dec	Jan	Feb	Mar	Apr*	May*	Jun*	Jul*	Aug	Sep
1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1

* Channel maintenance flow recommendations for the spring runoff period are defined in Appendix 1.

INTRODUCTION

Overall Approach

This report was compiled around a framework recognizing important components of an aquatic ecosystem and their relationship to stream flow. The results and analyses reported represent a continuing evolution from early Wyoming Game and Fish Department (WGFD) instream flow reports, which focused solely on sport fish species and maintenance-level instream flow recommendations, toward a focus consistent with contemporary understanding of stream ecosystems and fisheries management. In conducting and reporting instream flow studies, the WGFD develops recommendations based largely on concepts and strategies advocated by the Instream Flow Council (IFC), an organization of state and provincial fishery and wildlife management agencies (Annear et al. 2004). These recommendations include consideration of three policy components (legal, institutional, and public involvement) and five riverine components (hydrology, geomorphology, biology, water quality and connectivity; Annear et al. 2004). Sections and headings throughout this report were selected to generally reflect those components. By using the 8 components as a guide, we develop instream flow recommendations that are consistent with Wyoming's legal and institutional environment to maintain or improve important fishery resources for public benefit.

Legal and Institutional Background

The Wyoming Game and Fish Department manages fish and wildlife resources under Title 23 of Wyoming statutes (W.S.). The WGFD was created and placed under the direction and supervision of the Wyoming Game and Fish Commission (Commission) in W.S. 23-1-401 and the responsibilities of the Commission and the Department are defined in W.S. 23-1-103. In these and associated statutes, the Department is charged with providing " . . .an adequate and flexible system for the control, propagation, management, protection and regulation of all Wyoming wildlife." The WGFD mission statement is: "Conserving Wildlife - Serving People" while the Fish Division mission statement details a stewardship role toward aquatic resources and the people who enjoy them. In a 2005 policy statement, the Commission formally assigned responsibilities for implementation of instream flow water rights to the WGFD and specified procedures for notification of the Commission of instream flow activities.

The instream flow law, Wyoming Statute 41-3-1001-1014, was passed in 1986 and establishes that "unappropriated water flowing in any stream or drainage in Wyoming may be appropriated for instream flows to maintain or improve existing fisheries and declared a beneficial use..." The statute directs that the Game and Fish Commission is responsible for determining stream flows that will "maintain or improve" important fisheries. The Game and Fish Department fulfills this function under the general policy oversight of the Commission. An application for an instream flow water right is signed and submitted by the Wyoming Water Development Commission (WWDC) and, if approved by the State Engineer, the WWDC holds and administers the right on behalf of the state. The priority date for the instream flow water right is the day the application is received by the State Engineer.

The word "fishery", which is referenced throughout the instream flow legislation is a key concept that affects the determination of how much water is needed for instream flow purposes. From a natural resource perspective, a fishery includes the diverse fish habitats of the stream channel, riparian zone and floodplain as well as the processes of sediment flux and riparian vegetation development that sustain those habitats. To maintain the existing dynamic character of the entire fishery, instream flows must maintain the stream channel and its functional linkages to the riparian corridor and floodplain to perpetuate habitat structure and ecological function. The State Engineer has concluded that such channel maintenance flows are not consistent with the legislative intent of the instream flow statute. Therefore,

until the institutional climate and interpretation of state water law changes, channel maintenance flow recommendations are not included on instream flow applications. Channel maintenance flow requirements are presented in Appendix 1 of this report, should opportunities arise in the future to apply for an instream flow water right for this important component of the hydrograph.

Through early May 2006, the WGFD has forwarded 97 instream flow water right applications to the WWDC for submission, while the state engineer has permitted 55, and the Board of Control has adjudicated 4. Recently, we have focused on small headwater streams supporting native cutthroat trout. For example, studies were conducted from 1998 to 2003 on thirteen Greybull River tributary stream segments containing YSC (*Oncorhynchus clarki bouvieri*; Dey and Annear 2004). This document continues that focus by presenting study results and instream flow recommendations for a YSC stream in the South Fork Shoshone River drainage.

Yellowstone Cutthroat Trout

Marquette Creek was identified as an important fishery on the basis of its role in sustaining YSC. The Yellowstone cutthroat trout was petitioned for listing under the Endangered Species Act in 1998. In February 2001 the Fish and Wildlife Service (FWS) completed a 90-day petition review finding that the petitioners failed to present adequate information indicating that listing may be warranted. In January 2004, a suit was brought against the FWS alleging that this finding did not follow the tenets of the review process. In December 2004, the 9th Circuit Court overturned the FWS 90-day ruling on the basis that proper procedures were not followed and ordered the FWS to conduct a 12-month review. In February 2006 the FWS issued a finding that listing YSC as Threatened or Endangered is not warranted. Against this backdrop, the WGFD continues management efforts to protect and expand YSC populations (WGFD 2005). Securing adequate instream flow water rights is a prominent component of these efforts. Instream flow protection will help ensure the future of YSC in Wyoming by protecting existing base flow conditions against future consumptive and diversionary demands (which are presently unknown). Additional water rights for channel maintenance are still needed to ensure persistence of long-term habitat and maintain existing fisheries for future generations. .

Yellowstone cutthroat trout historically occupied Wyoming waters in the Snake River and Yellowstone River drainages, including the tributary Wind/Bighorn and Tongue River drainages (Behnke 1992, May et al. 2003). More recent distributional information is summarized in May (1996), Kruse et al. (1997), Dufek et al. (1999), and May et al. (2003). In 2001, fisheries experts from Wyoming, Montana, and Idaho compiled information on YSC populations including genetic status and population demographics (May et al. 2003). This project identified conservation populations and assessed the relative extinction risk among populations. Of the extant populations, those in the Greybull River and tributary Wood River contain genetically pure populations that span a large geographic area (Kruse et al. 2000) and hence were targeted first for instream flow studies during 1997 through 2003.

Marquette Creek was identified as an instream flow prospect following discussions with the Cody Regional Fisheries Crew and Aquatic Habitat Biologist and review of available information. Marquette Creek stood out during efforts to rank basins and streams according to miles of stream habitat occupied by genetically pure Yellowstone cutthroat trout (Annear and Dey 2006). Kruse et al. (2000) identified Marquette Creek as one of four YSC populations with high genetic purity and fish numbers (the others were Greybull River, Wood River, and the South Fork Shoshone River).

Public Participation

The public has several opportunities to be involved in the process of identifying instream flow segments or commenting on instream flow applications. First, people can make us aware at any time of important fisheries to consider for instream flow filings. We develop annual work schedules and 5-year plans that are available for public review and comment. The State Engineer is required to conduct a public hearing on the proposed instream flow water right to gather information for consideration before issuing a decision on the instream flow water right application. Prior to this hearing, the WGFD often conducts an informal information meeting to distribute information about the instream flow study (i.e. this report) and answer questions. Additional presentations to community or special interest groups also provide opportunity for discussion.

Meeting with landowners adjacent to or immediately downstream from instream flow segments is vital for sharing information about aquatic resources and the instream flow study and sometimes for securing access to conduct the instream flow study. While most instream flow segments are delineated on public land where un-appropriated water remains, landowners are usually given the opportunity to consider an instream flow segment on streams crossing their property.

Objectives

The objectives of this study were to 1) quantify year-round instream flow levels that maintain base-level Yellowstone cutthroat trout habitat, 2) provide the basis for filing an instream flow water right application to maintain hydraulic conditions for YSC, and 3) identify channel maintenance flows that maintain long-term trout habitat and related physical and biological processes. The audience for this report is broad and includes the State Engineer and staff, the Water Development Commission and staff, aquatic habitat and fishery managers, interest groups like Trout Unlimited and anyone interested in instream flow water rights in general or an instream flow water right on Marquette Creek, in particular.

STUDY AREA

Marquette Creek Basin Description

Marquette Creek flows into the South Fork Shoshone River at the upper end of Buffalo Bill Reservoir, about 10 miles west of Cody, Wyoming (Figure 1). Basin elevation ranges from about 5,374 feet at the mouth of Marquette Creek to 10,941 feet atop Carter Mountain. The basin's primary aspect is north facing. Precipitation at a weather station on the South Fork Shoshone River (481855) averaged 12 inches over the period 1970 – 2000 but precipitation would be greater at higher elevations in the Marquette Creek basin. Marquette Creek basin (hydrologic unit code 100800130303) area is 65 square miles and is about 4% of the total South Fork Shoshone River basin area (Figure 1). Land ownership in the basin is about 10% Shoshone National Forest in the headwaters of Marquette Creek, 30% Bureau of Reclamation or Bureau of Land Management and about 60% private.
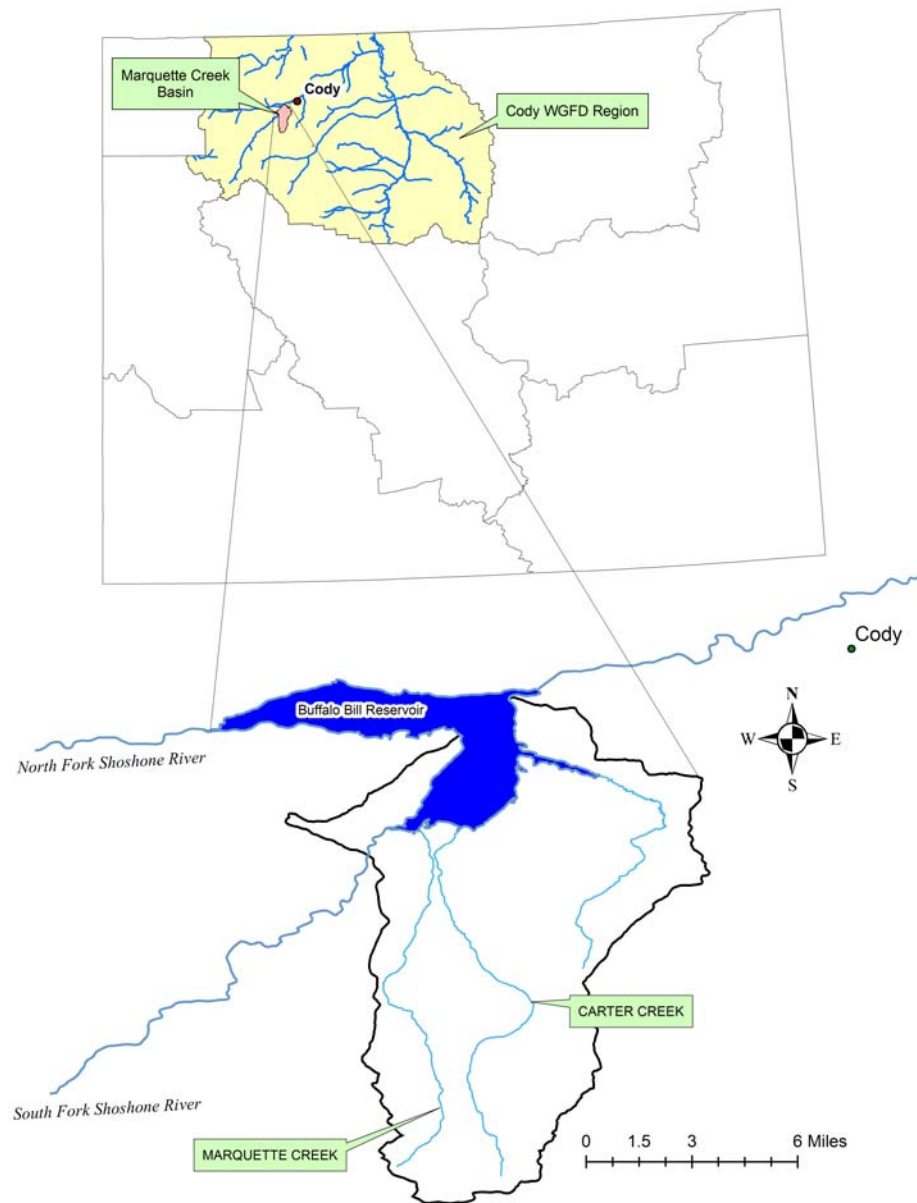
Figure 1. Location of Marquette Creek basin, WY (hydrologic unit code 100800130303).

Geology

Marquette Creek and its tributaries are high-elevation Absaroka Mountain streams with high channel slopes, unstable substrates, and large annual discharge fluctuations. These characteristics derive from the geologically young nature of the Absaroka Mountain Range which are remnants of a broad volcanic plateau that continues to erode as regional uplift occurs (Lageson and Spearing 1988). Igneous rock of the Wiggins Formation and Sunlight Group underlie the headwaters of Marquette Creek. Landslide deposits of this material occur from upper elevations downstream approximately to the middle of the basin. Various shale deposits (Frontier Formation, Thermopolis Shale, Cody Shale) comprise the

bedrock units in the lower portion of the basin. Annual precipitation is primarily snow, which leads to large fluctuations in annual discharge, including torrential spring flows during snowmelt runoff (Curtis and Grimes 2004). High snowmelt runoff easily moves erodible volcanic material resulting in stream channels that shift regularly, transport a lot of sediment and offer limited fish habitat. Earthen slumps are common and influence stream channel patterns by sometimes directly blocking or altering stream flow and providing large sediment supplies for eventual transport. Valley vegetation communities respond to mass wasting events with colonizing species, often aspen, establishing on denuded hill slopes.

From Rosgen's (1996) level I geomorphic classification, the V-shaped Marquette Creek valley conforms to valley type II. Stream channels throughout the upper elevations of Marquette Creek basin would be primarily classified as "A" and "B" from inspection of 1:24,000 scale topographic maps. The stream channel at the lower end of the instream flow segment (segment location is described in a later section) is a B3 channel type (Table 2), reflecting a cobble bed and moderate entrenchment, slope and width-depth ratios. The floodplain is narrow, usually less than 10 feet. Additional channel measurements are provided in Appendix 2 for reference.

Table 2. Stream channel measurements at the Marquette Creek study site.

Channel Feature	Value
Mean riffle bankfull width (ft)	9.0
Mean depth (ft)	0.55
Cross section area (ft2)	6.4
Entrenchment ratio	1.56
*D50 (mm)	67
Slope (ft./ft.)	.0705
Sinuosity	1.31
Stream Type	B3a

* D50 is the median particle size on a cumulative frequency plot.

B3 channels are very stable in pattern and profile (Rosgen 1996). Sediment is transported through but relatively little net removal or deposition occurs. Periodic pulses of high flow approximating a natural hydrograph remove fine organic sediment accumulations that might otherwise change ecosystem function under a reduced flow regime. For example, accumulated organic sediment might impair oxygenation of trout eggs and ultimately reduce or limit trout populations. Periodic bankfull and higher flows to maintain floodplain features are developed in Appendix 1.

South Fork Shoshone Basin Hydrology

No gage records exist for Marquette Creek. The nearest currently operating USGS gage is on the South Fork Shoshone River near Valley (06280300), approximately 23 miles upstream from the mouth of Marquette Creek. The period of record spans 47 years from October 1956 to September 1958 and October 1959 to the current year (2006). Irrigation diversions for about 450 acres occur upstream of the gage and basin area is 297 mi^2. An annual flow exceedance curve illustrates the relative magnitude and frequency of daily flows (Figure 2; HabiTech 2004).
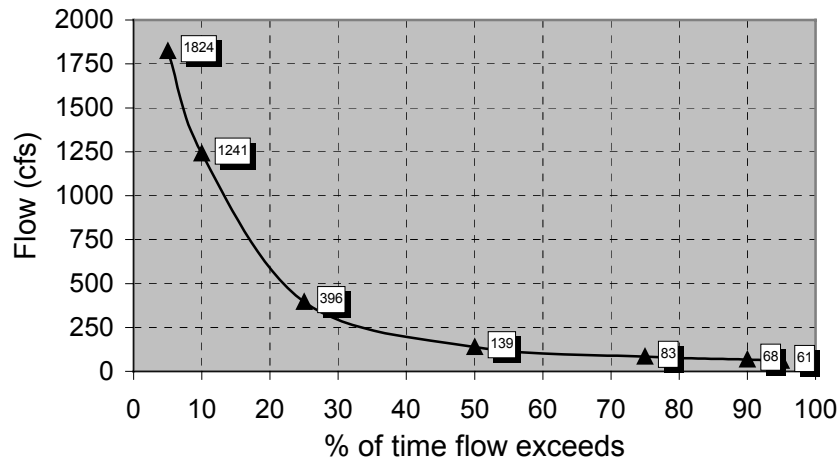
Figure 2. Flow exceedance for South Fork Shoshone River gage 06280300.

Stream flows are typical of a snowmelt runoff stream with flow peaks occurring between May 16 and July 5 (median peak flow date is June 14). Annual flow minima occur in winter, usually January or February (median date is January 24; Figure 3). While a wide variety of statistics can describe hydrology, annual stream flow variation (ASFV) and critical period stream flow (CPSF) from Binns and Eiserman (1979) and Binns (1982) are listed in Table 3 because these parameters are calculated for Marquette Creek later in this report. Annual stream flow variation is the ratio of the instantaneous annual peak flow to the annual low flow and averages a moderate 80% at the South Fork Shoshone River gage (Table 3). Suitability for trout expressed in a habitat score would be lower if ASFV was above 100 (Binns 1982). Conversely, habitat suitability would be considered higher if ASFV was below 40. The critical period stream flow is the average August 1 through September 15 flow expressed as a percent of average daily flow and averages 78%. This CPSF value represents relatively high flow levels in late summer and indicates trout habitat is likely to be high during this time of year compared to streams with low summer flows. Values of CPSF less than 55% would result in a lower trout habitat score.

Table 3. South Fork Shoshone River hydrologic statistics.

	Annual Stream Flow Variability (ASFV; annual peak flow / lowest daily flow	Critical Period Stream Flow (CPSF; Aug 1 – Sep 15 average flow / average annual flow
Mean (%)	80	78
Range (%)	34-167	51-125
n (years)	48	47
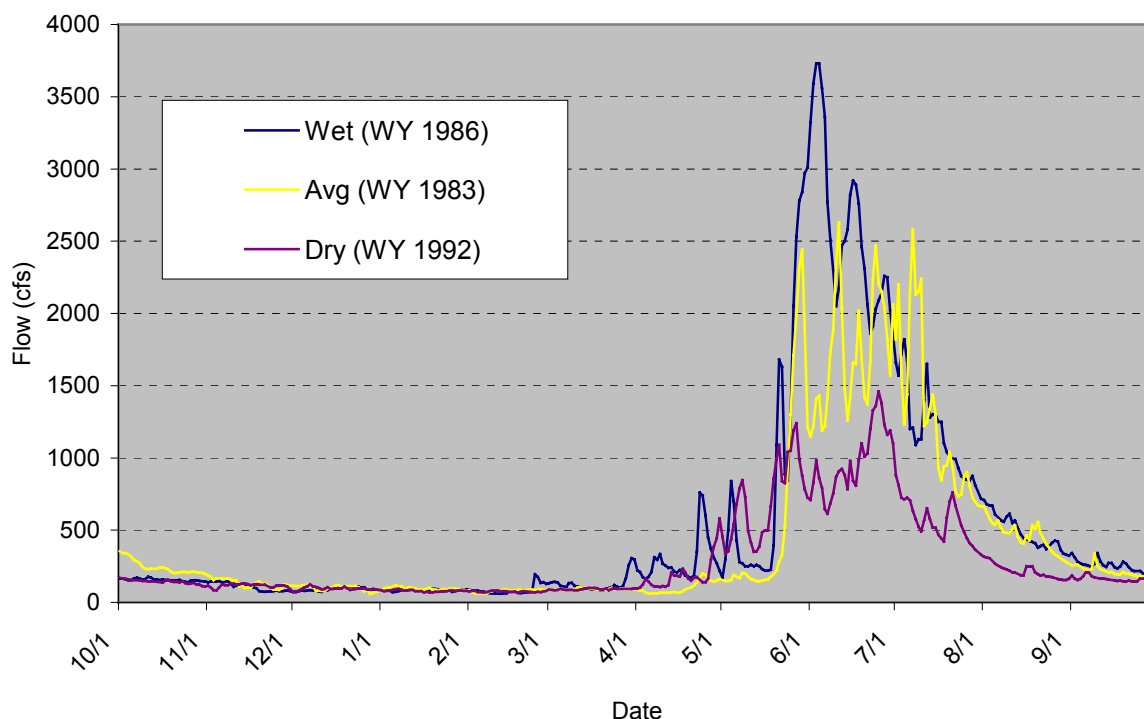
Figure 3. South Fork Shoshone River representative hydrographs from water years falling into three exceedance classes (wet 0-10%; average 30-70%; dry 90-100%).

To further illustrate basin hydrology, three annual hydrographs from the South Fork Shoshone River are plotted in Figure 3. Spanning the range from wet to dry years, the hydrographs show that annual low flows occur in the winter and at a consistent level regardless of runoff volume. Most years have multiple high flow events occurring between early-May and mid-July. Peak flow magnitudes differ markedly as expected for a comparison of wet to dry years. Also noteworthy, since cutthroat trout are spring spawners, is flows often begin to rise in April and sometimes March. Base flow recession occurs throughout summer with near base flow levels attained by October.

Flow magnitudes and timing in tributaries like Marquette Creek are likely to differ slightly on a local level from the South Fork Shoshone River gage data due to local precipitation patterns and other factors. But the long-term shape of the hydrograph should be similar to those illustrated above since the South Fork Shoshone basin upstream from Buffalo Bill Reservoir is relatively uniform in geology, land cover and management.

Upland and Riparian Resources

Upland vegetation in the Marquette Creek basin ranges from shrub-grassland steppe at lower elevations through montane coniferous forests to high elevation alpine moss-lichen-forb communities. Spruce-fir forests blanket mid-elevation regions of the Marquette Creek basin, especially on north facing slopes. South slopes and ridge tops often contain open grass or shrub communities and whitebark pine, limber pine and junipers occur occasionally. A severe outbreak of fir beetles during a drought in the late 1990's and early 2000's has resulted in high Douglas fir mortality throughout the South Fork Shoshone basin, including the Marquette Creek basin and much of Carter Mountain. The Forest Service conducted a salvage sale for fuel reduction and about 6 million board feet of timber were removed in 2004 and 2005

(M. Ritz, Shoshone National Forest, personal communication). The region receives high recreational use from hunters, ATV enthusiasts, horseback riders, snowmobiles, and firewood gatherers. The 2-track trail network provides access to 4X4s, ATVs and other transportation means. Where these roads and trails cross Marquette Creek, significant erosion and sediment inputs are apparent.

Riparian irrigated meadows occur on private land along lower Marquette Creek. Much of the uplands along Marquette Creek on private land are grazed by livestock with Hunt Oil the chief operator. From the Forest Service boundary upstream, the riparian zone is largely herbaceous vegetation with a few shrubs (mostly willow) and occasional conifers. The riparian zone rarely extends beyond 10 feet on each side of the stream. The Belknapp Allotment is the primary grazing permit on the Forest on the East end of Carter Mountain and allows 252 cow/calf pairs from July 1 through September 24. The Marquette Creek basin provides part of one of three pastures for this allotment.

Fishery Resources

The fish community in the South Fork Shoshone River basin upstream of Buffalo Bill Reservoir includes native YSC (Figure 4), mountain whitefish *Prosopium williamsoni*, mountain sucker *Catostomus platyrhynchus*, longnose sucker *Catostomus catostomus,* white sucker *Catostomus commersoni* and longnose dace *Rhinichthys cataractae.* Introduced species include rainbow trout *Oncorhynchus mykiss*, brook trout *Salvelinus fontinalis* and brown trout *Salmo trutta*. The fine-spotted Snake River form of Yellowstone cutthroat trout has also been introduced in the basin. Amphibians include leopard frog *Rana pipiens*, boreal chorus frog *Pseudocris triseriata maculata*, Columbia spotted frog *Rana luteiventris* and boreal toad *Bufo boreas*.

Figure 4. Yellowstone cutthroat trout (photo by Wyoming Game & Fish Department).

In the past, the fishery management focus in the South Fork basin was on providing diverse angling opportunities by supplementing natural populations with stocked fish. Cutthroat trout, brook trout and rainbow trout were stocked throughout the South Fork Shoshone drainage from the early 1900's

until the late 1980's (Kent 1984). Today, the fishery management focus is on providing wild trout fisheries, particularly brown trout. Marquette Creek might not be considered a premier destination for many anglers due to its small size and the fact that it is mostly under private ownership. But these facts also help create a high conservation value for the fishery. An irrigation diversion in lower Marquette Creek acts as a migration barrier and prevents exotic salmonids like rainbow trout from Buffalo Bill Reservoir (South Fork Dike Pond) moving upstream and hybridizing or competing with Marquette Creek YSC. Marquette Creek is significant for fish conservation because a substantial population of approximately 2900 genetically pure YSC reside in the stream (Kruse et al. 2000). This population translates to approximately 1900 breeding age fish. Conservation biologists generally regard a population size of 500 breeding fish as a minimum level for maintaining genetic diversity and the Marquette Creek YSC are one of only four known populations in the Bighorn Basin and outside Yellowstone National Park to exceed that level (Kruse et al. 2000).

Historical fish sampling in Marquette Creek is limited to samples collected in July 1997 by Carter Kruse as part of a basin-wide YSC study (Kruse 1998). The only fish species documented in Marquette Creek are YSC, Snake River cutthroat trout and, in the very downstream-most stretch of stream below the irrigation diversion, brook trout. Other potential native fish species, longnose dace and mountain sucker, were not documented.

Instream Flow Segment

The lower 9 miles of Marquette Creek abut privately owned land and the headwaters occur on the Shoshone National Forest (Figure 5). From measurements on 1:24,000 scale maps in AllTopo V7 (iGage 2003), Marquette Creek extends about 2.2 miles on National Forest. Including all the perennial tributaries on a 1:24,000 scale map, there are approximately 5 stream miles in the drainage network above the Forest Service boundary. A 0.5-mile long instream flow segment was identified from an un-named tributary downstream to the Forest Service Boundary (Figure 5, Table 4). The lower boundary was identified because it marks the beginning of public land. The upper boundary marks a significant hydrologic break where Marquette Creek upstream of the tributary is likely to have markedly less water and a different relationship between habitat and water quantity. In addition to the 0.5-mile instream flow segment, about 4.5 stream miles in the upper Marquette Creek basin, upstream of the instream flow segment, will be indirectly protected. Indirect protection occurs by virtue of the fact that any new water users in the headwaters must pass enough water to fulfill the downstream senior instream flow appropriation.

Table 4. Marquette Creek instream flow segment location and length from AllTopo® software.

Length (mi)	Approximate UTM (Z12, NAD27)		Segment Description
	Upper	Lower	
0.5	641716 E, 4908837 N	641755 E, 4909612 N	Un-named tributary downstream to Forest Service boundary
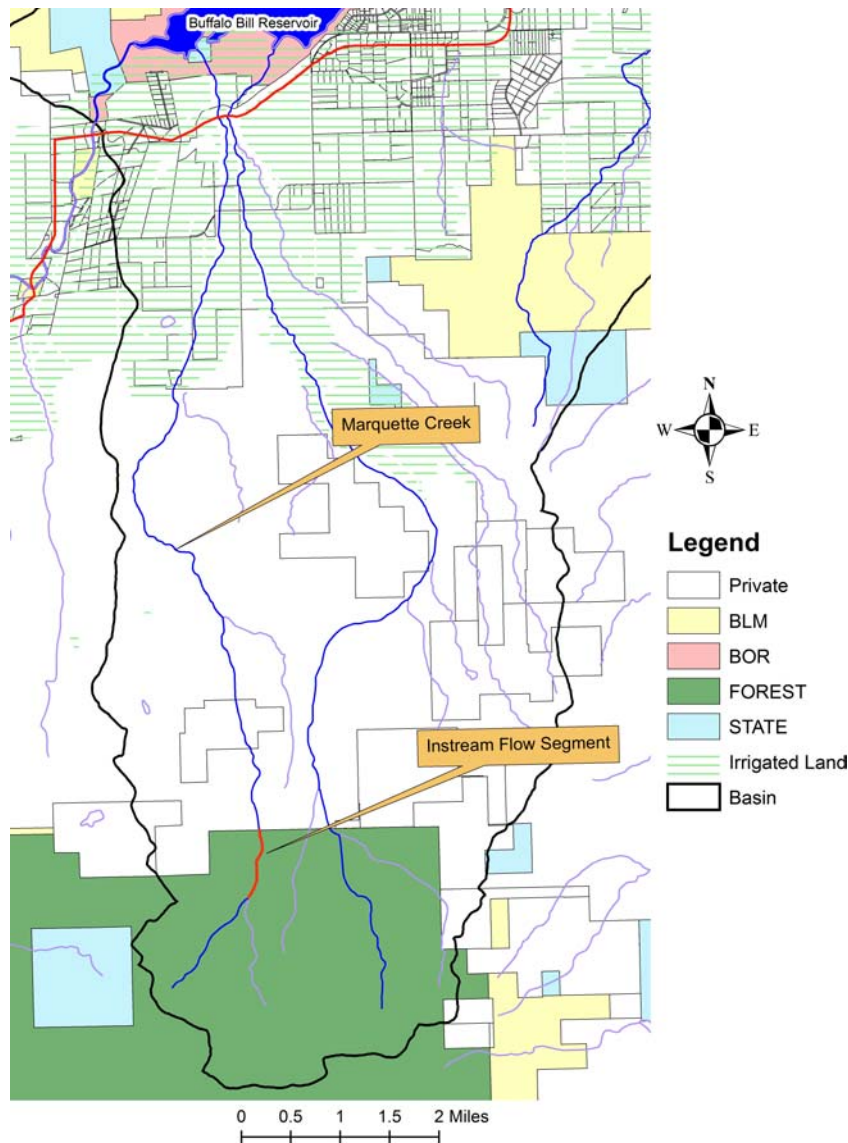
Figure 5. Marquette Creek instream flow segment.

METHODS FOR DEVELOPING FLOW RECOMMENDATIONS

This section presents methods used in developing fish flow recommendations for a Marquette Creek instream flow water right application. However, if flows are limited to only the instream flow water right recommendations developed from these methods, the fishery will suffer over the long term because annual patterns of floodplain inundation and sediment flux would not be functioning to maintain the stream channel and associated habitat. Channel maintenance flow recommendations are developed in Appendix 1 to address a broader interpretation of fishery maintenance. Should opportunities arise in the future to file instream flow water rights for long-term maintenance of Marquette Creek aquatic environments, Appendix 1 will provide a valuable reference.

The conservation of Yellowstone cutthroat trout in Wyoming is a high priority and the reason Marquette Creek was selected for an instream flow water right. Marquette Creek provides habitat for adult (≥6 inches), spawning, juvenile (3-6 inches) and fry (<3") Yellowstone cutthroat trout. However, most of the habitat quantity and quality occurs on private land, downstream from the Forest. On the Forest, a steep channel slope with associated high water velocities and few deep pools provide limited adult habitat. Also, stream bottom rocks (substrate) are too large for spawning in most places. Therefore, flow recommendations were developed to maintain the limited adult habitat on the Forest and the flow needs of spawning, juvenile and fry life stages within the instream flow segment were not addressed.

Estimating Marquette Creek Hydrology

HabiTech, Inc. (Laramie, WY) estimated mean annual flow (also called "average daily flow" or ADF), annual flow duration, monthly flow duration, and flood frequency for the Marquette Creek instream flow segment (HabiTech 2004). HabiTech calculated average daily flows from the contributing basin area model of Miselis et al. (1999). This model was developed from gages in Absaroka Mountain streams and is similar to the approach of Lowham (1988). The basin area at the downstream end of the instream flow reach was used. A dimensional analysis approach was used to develop both annual and monthly flow duration information. Dimensionless duration tables were created for the South Fork Shoshone near Valley gage by dividing each duration class by the mean annual flow (i.e. Q_W / Q_{AA}). The dimensionless flow value for each annual and monthly percentile was then multiplied by the estimated average annual flow to develop flow duration values. A similar approach was used to develop the flood frequency series. For further details, see HabiTech (2004).

The basin area approach used by HabiTech (2004) is based on Absaroka Mountain gage data to more accurately reflect local conditions. Alternative approaches for estimating Marquette Creek hydrology include applying the Lowham (1988) basin characteristic approach or the recently refined basin characteristic approach described in Lowham et al. (2003). These methods result in similar or higher flow estimates. For example, HabiTech (2004) calculated 1.0 cfs average daily flow compared to 1.5 cfs using Lowham (1988). In another example, applying Lowham (2003) yields an October average flow of 1.3 cfs compared to 0.7 cfs from the Miselis et al. equation. HabiTech (2004) estimates an October 50% duration flow of 0.37 cfs. Differences on this order are consistent for all months and tributaries. Therefore hydrology estimates used in this report are likely conservative and, if in error, are most likely lower than actually occur in the streams.

Average daily flow estimates from the HabiTech report were used in applying the Habitat Quality Index and Habitat Retention models (described below). The 1.5-year return interval on the flood frequency series was used to estimate bankfull flow (Rosgen 1996) for use in the Habitat Retention model and for developing channel maintenance flow recommendations (Appendix 1). Channel maintenance calculations also used the 25-year peak flow estimate from HabiTech (2004). The monthly flow duration series was used in developing winter flow recommendations. Throughout this report, the term "exceedance" is used, as in "20% exceedance flow". The 20% exceedance flow refers to the flow level that would be exceeded 20% of the time. As such, it is a higher flow level than the 50% or 80% exceedance flow.

Flow measurements collected during instream flow habitat studies are included in this report (Table 7). HabiTech (2004) compared their hydrological estimates to these flow measurements and concluded that their predictions were reliable.

Predicting Fish Habitat Using Instream Flow Models

The term "habitat" is used frequently in this report. In most applications, "habitat" refers to the physical conditions of depth, velocity, substrate and cover – variables that change when discharge

changes. A full trout habitat description also includes temperature, dissolved oxygen, distribution and abundance of prey and competitor species, movement timing and extent, and other variables. The "physical" habitat modeled and discussed in this report covers the important dimensions of trout habitat that vary predictably as a function of flow. It is assumed that these aspects of trout habitat are important to the health and short-term persistence of trout populations.

Two modeling approaches described below were used to generate monthly fish-based instream flow water right recommendations. Development of fish flow recommendations for the winter, October through March, considered the need to retain natural flows during this critical period. Channel maintenance flow requirements are described in Appendix 1.

Habitat Retention

The Habitat Retention Method (Nehring 1979; Annear and Conder 1984) was used to identify the flow that maintains selected values of depth, velocity and wetted perimeter in riffles (Table 5). Maintaining depth, velocity and wetted perimeter criteria in riffles ensures that other habitat types like runs or pools remain viable (Nehring 1979). Fish passage between habitat types and benthic invertebrate survival are considered adequate at the flow level identified by the Habitat Retention Method. The flow identified by the Habitat Retention Method is important year round except when higher instream flows are required to meet other fishery management purposes.

Table 5. Hydraulic criteria for determining maintenance flow with the Habitat Retention method
(Annear and Conder 1984).

Category	Criteria
Mean Depth (ft)	0.20
Mean Velocity (ft/s)	1.00
Wetted Perimeter[a] (%)	50

a - Percent of bankfull wetted perimeter

Simulation tools and calibration techniques used for hydraulic simulation in PHABSIM (Bovee et al. 1998) are used with the Habitat Retention approach. The difference is that Habitat Retention does not attempt to translate depth and velocity information into conclusions about the amount of physical space suitable for trout life stages. The Habitat Retention Method focuses on riffle hydraulic characteristics so that fish passage and invertebrate production is maintained. The AVPERM model within the PHABSIM methodology is used to simulate cross section depth, wetted perimeter and velocity for a range of flows. The flow that maintains 2 out of 3 criteria in Table 5 for all riffle transects is then identified.

Habitat Quality Index

The Habitat Quality Index (HQI; Binns and Eiserman 1979; Binns 1982) was used to determine trout habitat levels over a range of late summer (July through September) flow conditions. Most of the annual trout production in Wyoming streams occurs during the late summer, following peak runoff, when longer days and warmer water temperatures stimulate growth. The HQI was developed by the WGFD to measure trout production in terms of nine biological, chemical, and physical trout habitat attributes. Each attribute is assigned a rating from 0 to 4 with higher ratings representing better trout habitat. Attribute ratings are combined in the model with results expressed in trout Habitat Units (HU's), where one HU is defined as the amount of habitat quality that will support about 1 pound of trout/acre.

In the HQI analysis, habitat attributes measured at various flow events are assumed to be typical of late summer flow conditions. For example, stream widths measured in June under high flow conditions are considered an estimate of stream width that would occur if that flow level were a base flow occurring in September. Under this assumption, HU estimates are extrapolated through a range of potential late summer flows (Conder and Annear 1987). Linear equations of velocity and cover at different flow levels were used to calculate ratings. In calculating Habitat Units over a range of discharges, temperature, nitrate concentration, invertebrate numbers, and eroding banks were held constant. HQI results were used to identify the flow between July 1 and September 30 needed to maintain existing levels of Yellowstone cutthroat trout production (Table 6).

Article 10, Section d of the Instream Flow statute states that waters used for providing instream flows "shall be the minimum flow necessary to maintain or improve existing fisheries". The HQI is used to identify a flow to maintain the existing fishery in the following manner: the number of habitat units that occur under normal July through September flow conditions is quantified and then the flow that maintains that level of habitat is identified. To define July through September flow conditions, we review both measured flows and estimated 50% monthly exceedance flows for the July through September period. The August 50% monthly exceedance flow was used as a reasonable estimate of normal late summer flow levels and is consistent with how the HQI was developed (Binns and Eiserman 1979).

Maintaining Fish Habitat In Winter

Natural winter (October through March) flow levels are recommended to maintain the Yellowstone cutthroat trout populations in Marquette Creek. The following discussion provides the basis for this recommendation:

Scientific understanding of winter trout habitat and the interaction between trout behavior, their habitat and ice and snow has increased considerably over the last 60 years (Needham et al. 1945, Reimers 1957, Butler 1979, Cunjak 1988, Cunjak 1996, Prowse 2001a and 2001b, Greenberg et al. 2005). Prowse (2001a and 2001b) provides an extensive review of the wide range of effects ice processes have on the hydrologic, biologic, geomorphic, water quality and connectivity characteristics of riverine resources and fisheries. Ice processes in particular may limit habitat. For example, suspended ice crystals (frazil ice) can cause direct trout mortality through gill abrasion and subsequent suffocation. Frazil ice may also indirectly increase mortality by limiting available habitat, causing localized de-watering, and causing excessive metabolic demands on fish forced to seek ice-free habitats (Brown et. al 1994, Simpkins et al. 2000, Annear et al. 2002, Barrineau et al. 2005, Lindstrom et al. 2004). Pools downstream from high gradient frazil ice-forming areas can accumulate anchor ice when woody debris or surface ice provides anchor points for frazil crystals (Brown et. al 1994, Cunjak and Caissie 1994). Such accumulations may result in mortalities if low winter flows or ice dams block emigration.

Mortalities can occur if fish are forced to move when water temperatures are near freezing, such as to avoid the physical effects of frazil ice or if changing hydraulic conditions force them to find areas of more suitable depth or velocity. The extent of impacts is dependent on the magnitude, frequency and duration of frazil events and the availability of alternate escape habitats (Jakober et. al, 1998). Juvenile and fry life stages are typically impacted more than larger fish because younger fish inhabit shallower habitats and stream margins where frazil ice tends to concentrate. Larger fish that inhabit deeper pools may endure frazil events with little effect if they are not displaced. In contrast, refuge from frazil ice may occur in streams with groundwater influx, pools that develop cap ice and segments where heavy snow cover causes stream bridging (Brown et al. 1994). Recent studies in Wyoming document complex interactions between localized ice conditions and trout habitat suitability (Barrineau et al. 2005).

The complexities of variable icing patterns (for example, frazil and surface ice often appear and disappear over widely ranging spatial and temporal scales) make direct modeling of winter trout habitat highly difficult if not impossible. Even cases that can be modeled, for example a stable ice cap over a simple pool, may not yield a result worthy of the considerable time and expense necessary to calibrate an ice model. The IFC (Annear et al. 2004, Pp. 106) recognizes the challenges of developing winter flow prescriptions with the following statement:

> *Unfortunately, the tools to quantify the relation between flow and favorable ice conditions, and habitat, are limited at this time. In the face of this uncertainty, managers should take a conservative approach when their actions or those of others will result in modification of winter flow regimes, either by additions or depletions*.

For Wyoming Rocky Mountain headwater streams, a conservative approach to meeting the instream flow law's requirement of developing flow recommendations to maintain existing fisheries is to simply recommend the existing natural winter flow level. That approach was adopted for Marquette Creek. The scientific literature indicates that already harsh winter habitat conditions would become more limiting if winter water depletions were to occur and force trout to move more frequently, change the frequency and severity of ice formation, distribution and retention, and reduce the trout holding capacity of the few large pools.

Indirect methods, such as the Habitat Retention Method employed by the WGFD, are an alternative way of indexing winter trout habitat changes to flow and this approach was used exclusively in the past to set winter flow recommendations for many instream flow segments. Habitat Retention analyses are still conducted to ensure that riffle hydraulics are maintained under ice-free conditions. When natural winter flows in mountain streams are greater than those from Habitat Retention, the natural winter flow will become the instream flow recommendation.

Another indirect method is developing hydrologic standards for universal application across Wyoming. Hubert et al. (1997) found this approach deficient due to the variable nature of winter trout habitat among streams and poor gage records often associated with the winter season. For this reason, we do not believe the 50% monthly exceedance provides an appropriate estimate of naturally occurring winter flow. It is more conservative from the standpoint of maintaining fisheries to recommend the higher flows of a 20% monthly exceedance. This assures that even in cases where flow is underestimated due to poor gage records or other estimation errors, flow levels approximating the natural winter condition will be protected.

Combining Methods to arrive at Instream Flow Recommendations

The fishery functions and associated time periods summarized in Table 6 show how the Habitat Retention, HQI and natural winter flow approaches described above were applied to Marquette Creek on a seasonal basis. Because the proposed Marquette Creek instream flow segment does not contain a full complement of habitat features to support all life stages (those habitats occur downstream), only adult fish needs are reflected in Table 6. The instream flow recommendation for any month where two or more recommendations apply is based on the recommendation that yields the higher flow. Natural flows during the October through March winter months are recommended for high mountain streams like Marquette Creek (Table 6). The Habitat Retention approach provides a base flow but is not used for instream flow recommendations when other aspects of fishery maintenance require higher flows. The HQI applies to adult trout growth during the months of July, August and September and is the default method for those months. Channel maintenance flows perform their function during runoff in April, May, June and July but are not used in the instream flow water right application as described in the *Introduction*.

Table 6. Yellowstone cutthroat trout life stages and months considered in developing instream flow recommendations. Numbers indicate the method used to determine flow requirements and green shaded cells indicate primary methods for flow recommendations in this study.

Life Stage and Fishery Function	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Survival and movement of all life stages	1	1	1	1	1	1	1	1	1	1	1	1
Adult growth							2	2	2			
All life stages long-term habitat[*]				3	3	3	3					

1=Natural winter flow or Habitat Retention, whichever is greater, 2=Habitat Quality Index, 3=Channel Maintenance.
* Channel maintenance flow recommendations are developed in Appendix 1.

Collecting Data at a Study Site

A 293-foot HQI study reach was established at UTM 641819E, 4909446N (Zone 12, NAD27) near the Forest Service boundary and downstream end of the instream flow segment (Figure 5 and 6). Re-rod pins were pounded into the banks to mark end points of riffle transects in three separate riffles within the HQI reach. The study site was visited on multiple dates to measure habitat features under a range of flow conditions (Table 7). In addition to collecting measurements for the HQI and Habitat Retention models, a Rosgen Level 2 channel survey was conducted (Rosgen 1996). This involves measuring channel pattern, profile, dimension, and sediment size (Appendix 2). This geomorphic information serves to classify the stream type and provides a basis for addressing questions of sediment supply, stream sensitivity to disturbance, channel response to flow regime changes and fish habitat potential. The data are also important for developing channel maintenance flow requirements. Channel measurements collected include measurements of at least 100 substrate particles, cross sectional area, longitudinal profile, and multiple bankfull width measurements. Channel pattern measurements of sinuosity, belt width, and meander length were measured with a tape.

Table 7. Dates and discharges when measurements were collected in 2004 at the Marquette Creek study site.

Date	Discharge (cfs)	Data Collected
May 4	1.3	Site reconnaissance
May 27	1.7	HQI, Habitat Retention
June 10	3.2	HQI, Habitat Retention
July 15	2.3	HQI, Habitat Retention, cross section & profile survey
August 17	1.1	WHAM*, pebble count, channel plan form

*Wyoming Habitat Assessment Methodology (Quist and Hubert 2004). The WHAM provides a general description of watershed features.

Relative percentages of pools, riffles, runs, etc. were determined using the classification scheme of Hawkins et al. (1993). Under this approach, channel units such as pools, riffles, and runs are identified by relative channel gradient, water velocity, surface turbulence, and depth. Channel unit lengths were determined by recording the paced length (about 3 feet per pace) of each channel unit encountered over a stream distance of at least 20X the bankfull width. A 594-foot reach, overlapping the HQI reach, was classified.

PHABSIM for Windows Version 1.2 was used to simulate riffle hydraulic features. Water surface elevations for all transects were simulated using stage-discharge relationships. We assessed water surface

predictions by looking for linearity of the log flow-log water surface elevation plot, low mean square error of regression, and parallel water surface profiles (Waddel 2001). The velocity set collected at 3.2 cfs served as the calibration source for distributing roughness among cells. Velocity calibration included comparison of predicted and measured velocities and examination of VAF plots (Waddel 2001). In calculating the wetted perimeter criterion (Table 5), bankfull discharge was estimated as the 1.5-year return interval flow of 8.0 cfs from HabiTech (2004). For applying the Habitat Retention depth criteria, an average daily flow of 1.0 cfs was used (HabiTech 2004). Average wetted stream width at 1.0 cfs was less than 20 feet (actually less than 7 feet from HQI measurements) so 0.20 was used as the default depth criterion.

For HQI analysis, the critical period stream flow and annual stream flow variation attributes were calculated using average daily flow (1.0 cfs) and peak flow (8.0 cfs) estimates from HabiTech (2004). Maximum water temperature was determined with an Optic StowAway® temperature recorder set to monitor water temperature at 1-hour intervals between May 25 and August 23, 2004. The HQI "substrate" attribute, a measure of invertebrates per square foot of streambed, was rated visually.

Flows For Other Important Ecosystem Components

The foregoing sections focus primarily on narrowly defined methods for maintaining short-term fish habitat. Additional biological issues include maintaining diverse riparian and floodplain vegetation and the community of animals that use these habitats. We assume that channel maintenance flow recommendations described in Appendix 1 would promote a healthy riparian assemblage of plants and animals resembling that of today. Such flows would serve to maintain the existing B channel described in an earlier section.

Existing Marquette Creek water quality is good in and upstream of the instream flow segment. That is, water temperature, turbidity, and various organic and inorganic constituents are believed to be at normal levels for a fairly pristine Absaroka Mountain stream. Baseline water chemistry values in the South Fork Shoshone River and tributaries are reported in Kent (1984). Flow recommendations in this report are expected to maintain water quality within natural bounds. If new water development were to occur in the Marquette Creek basin, water quality issues might bear re-examination.

Figure 6. Marquette Creek at 1.7 cfs (top), 3.2 cfs (middle), and 2.3 cfs (bottom). Riffle transect 1 is near the top of the photo and riffles 2 and 3 are further upstream.

RESULTS AND DISCUSSION

Hydrology

The South Fork Shoshone basin hydrologic conditions were relatively dry during 2004 when the instream flow study was conducted (Figure 7). Mean annual flow at the South Fork Shoshone River at Valley gage for water year 2004 was 266 cfs compared to a 405 cfs average (47 years of record). Average May, June and July flows were at the 68%, 81%, and 68% exceedance levels for those months. A Snotel site (09E09S) at an elevation of 8760 feet in the Marquette Creek watershed recorded 21.2 inches of precipitation in Water Year 2004 compared to a 30-year average of 27.4 inches.

The relatively low flows in 2004 did not limit our ability to study fish habitat versus flow relationships in Marquette Creek. Measurements collected over the range of 1.1 to 3.2 cfs (Table 7) allowed extrapolation down to less than 1.0 cfs and up to at least 8.0 cfs (see results below). On four of the five dates Marquette Creek was sampled, measured flows were near the estimated 50% monthly exceedance values (Table 8). In August, the measured flow of 1.1 cfs was relatively high compared to the estimated 50% August monthly exceedance value.

Table 8 lists key flow estimates from HabiTech (2004). Without a gage record on Marquette Creek, there is no basis for a direct measure of the reliability of estimated flows. HabiTech (2004) discuss the reliability of their estimates, noting that the WGFD measurements are within expectations and their approach based on the Miselis model yielded reasonable results. No evidence of bankfull or higher flows was observed during the 5 visits in 2004. For example, peak flow at the South Fork Shoshone River gage in 2004 occurred on June 10, the same date Marquette Creek was visited. The measured 3.2 cfs was below the bankfull level indicated by a break in the cross-section profile and a flat floodplain depositional area (Figure 6). HabiTech's estimated 8.0 cfs bankfull flow seems reasonable based on these observations.
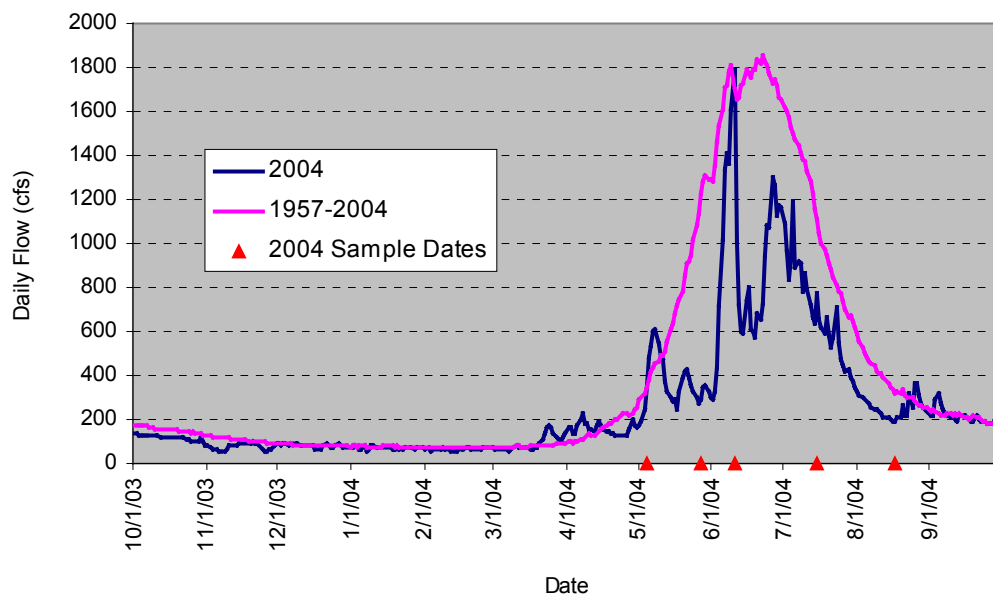

Figure 7. South Fork Shoshone River hydrology at USGS gage 06280300 for water year 2004 and for the period 1957 through 2004. Markers indicate dates of Marquette Creek sampling.

Table 8. Marquette Creek instream flow segment estimated hydrologic characteristics (HabiTech 2004).

Flow parameter		Estimated Flow (cfs)
Mean Annual		1.0
1.5 year peak		8.0
25 year peak		18
Spring Month	Estimated Monthly 50% Exceedance (cfs)	Date; Flow Measurement (cfs); Monthly Exceedance of Flow Measurement
May	1.5	May 3, 2004; 1.3; 55% May 27, 2004; 1.7; 44%
June	3.8	June 10, 2004; 3.2; 63%
Summer Month		
July	2.3	July 15, 2004; 2.3; 50%
August	0.78	August 17, 2004; 1.1; 28%
September	0.49	
Winter Month		Estimated Monthly 20% Exceedance (cfs)
October	0.37	0.46
November	0.26	0.33
December	0.20	0.25
January	0.19	0.22
February	0.18	0.20
March	0.19	0.23
April	0.30	0.53

Development of Fish Flow Recommendations

The macrohabitat survey tallied 76% fast-water channel units and 24% slow-water units (pools). Rapids were the most frequent fast water category (43%) followed by riffles (23%) and cascades (8%). Backwater and plunge pools were the most frequently identified pool types.

Habitat Retention

Average depth, average velocity, and wetted perimeter across three riffle transects as a function of flow are listed in Table 9. At riffle 1, velocity is the first hydraulic criterion met as flow declines from its bankfull level to 1.1 cfs. Next, the depth criterion is met at 0.70 cfs and the wetted perimeter criterion is met at 0.24 cfs. Thus, two of three hydraulic criteria (wetted perimeter and mean depth) are retained by a flow of 0.7 cfs across riffle 1 (Table 9). In a similar fashion, 0.80 cfs retains two of three criteria on riffle 2 and 1.1 cfs is required to meet criteria on riffle 3. Therefore, the flow that retains two of three criteria for all of the studied riffles is 1.1 cfs. Based on the Habitat Retention model, a flow of 1.1 cfs is necessary year round to maintain trout survival, movement and invertebrate production.

Table 9. Simulated hydraulic criteria for three Marquette Creek riffles. Bold indicates that the hydraulic criterion was met. Bankfull is 8.0 cfs. Flows meeting 2 of 3 criteria for each riffle are shaded.

	Mean Velocity (ft/s)	Mean Depth (ft)	Wetted Perimeter (ft)	Discharge (cfs)
Riffle 1	2.73	0.43	8.2	8.0
	1.72	0.38	6.0	3.2
	1.46	0.34	5.6	2.3
	1.25	0.30	5.4	1.7
	1.01	0.24	4.9	1.1
	0.82	**0.20**	4.8	0.70
	0.54	0.12	**4.1**	0.24
	0.51	0.11	3.9	0.20
Riffle 2	3.04	0.41	7.0	8.0
	1.78	0.30	6.4	3.2
	1.48	0.27	6.1	2.3
	1.25	0.26	5.6	1.7
	1.02	0.23	5.4	1.2
	0.81	**0.20**	5.2	0.80
	0.70	0.18	5.0	0.60
	0.47	0.16	4.3	0.30
	<0.47	<0.16	**<4.3**	<0.30
Riffle 3	2.26	0.38	9.8	8.0
	1.55	0.27	8.1	3.2
	1.36	0.24	7.5	2.3
	1.20	0.23	6.8	1.7
	1.04	**0.20**	6.4	1.2
	1.00	0.20	6.1	1.1[a]
	0.87	0.19	5.4	0.80
	0.68	0.15	**4.9**	0.46
	0.57	0.13	4.6	0.30

a - Discharge at which 2 of 3 hydraulic criteria are met for all riffles.

Habitat Quality Index

A maximum water temperature of 63° F was recorded July 19, 2004. This temperature falls in the 55 - 65º F band for a rating of "4" under Binns (1982) and reflects optimal thermal conditions. A water sample for analysis of nitrates was not collected; however, nitrate levels are not expected to change as a function of flow and this attribute was held constant at a rating value of "1". Stream banks were not eroding, earning a rating of "4". The substrate attribute was rated a "2" reflecting a moderate occurrence of aquatic invertebrates. Percent cover ranged between 9% and 14% and increased with flow. The cover rating changes from "0" to "1" when cover is greater than 10% of the wetted channel. By linear interpolation, the cover rating increases at flows greater than 1.3 cfs.

Peak habitat units occur between 2.4 and 5.1 cfs (Figure 8). Contributing to the peak are a combination of ideal water velocity (the velocity rating peaks between 2.4 and 5.1 cfs), adequate base flow (CPSF rating peaks at 0.56 cfs), minimal annual stream flow variation (ASFV rating peaks at 0.51

cfs), and greater than 10% cover (rating changes at 1.3 cfs). At flows greater than 5.1 cfs, higher velocities begin to limit the habitat quality.
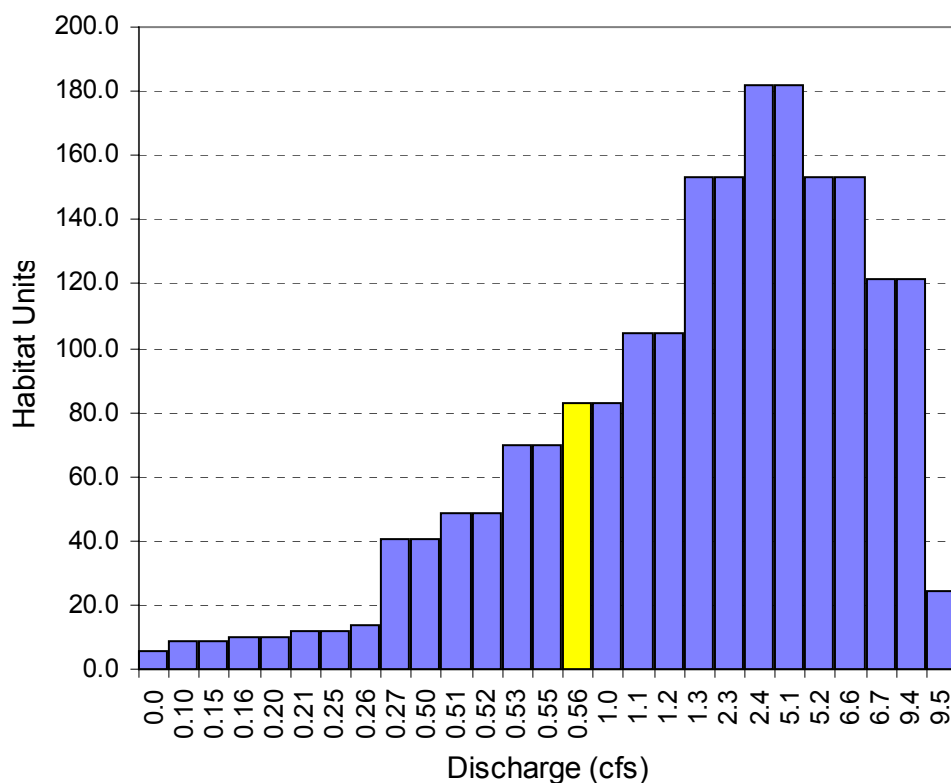

Figure 8. Habitat Quality Index for a range of flow levels. X-axis flows are scaled to show where changes in Habitat Units occur. The minimum flow to maintain existing habitat units is indicated by the light shaded bar.

Measured flows in the July through September period range from 1.1 to 2.3 cfs (Table 8). Estimated monthly streamflows that occur 50% of the time are: 2.3 cfs, 0.78 cfs, and 0.49 cfs for July, August and September (Table 8). The 0.78 cfs August value provides a reasonable estimate of normal late summer flow levels. At this flow, the stream provides 83 habitat units (Figure 8). The lowest flow that will maintain 83 habitat units is 0.56 cfs.

Based on the Habitat Retention method, a streamflow of at least 1.1 cfs is needed year round to maintain fish passage and invertebrate production. Therefore, the recommended July through September stream flow is 1.1 cfs. According to the HQI model results, such a flow will provide an improvement in fish production potential relative to current conditions (104 habitat units compared to 83 habitat units).

<u>Winter Flows and Habitat</u>

October through April 20% monthly exceedance flows in Table 8 are less than the 1.1 cfs Habitat Retention flow. To maintain opportunities for fish passage and invertebrate production, the habitat retention flow of 1.1 cfs is recommended.

INSTREAM FLOW WATER RIGHT RECOMMENDATIONS

Marquette Creek has important Yellowstone cutthroat trout habitat and a population of genetically pure trout. An instream flow filing will protect existing base flow conditions against unknown future consumptive and diversionary demands. About 0.5 miles of stream habitat will be directly protected and about 4.5 miles of headwaters will be indirectly protected if this instream flow application advances to permit status.

Marquette Creek instream flow recommendations to maintain short-term Yellowstone cutthroat trout habitat are summarized in Table 10. Although HQI results were analyzed and natural winter flows were estimated, riffle hydraulic results from Habitat Retention are the basis for the year round instream flow recommendation. A flow of 1.1 cfs will provide opportunities for fish movement throughout the year and ensure that riffle invertebrate production continues. Fish production in July, August and September will be improved by a flow of 1.1 cfs. Natural winter flow levels, up to 1.1 cfs, are recommended to minimize habitat constraints imposed by variable icing patterns in mountain streams.

Table 10. Marquette Creek instream flow recommendations for short-term fishery maintenance.

Monthly Flow Recommendations (cfs)											
Oct	Nov	Dec	Jan	Feb	Mar	Apr*	May*	Jun*	Jul*	Aug	Sep
1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1

* Channel maintenance flow recommendations for the spring runoff period are defined in Appendix 1.

Channel maintenance flows to preserve the long-term habitat and ecological functions that support the existing fishery are described in Appendix 1. Flow recommendations apply to the stream segment defined in Table 4.

Because data were collected from a range of habitats and simulated over a wide flow range, additional data collection under different flow conditions is not likely to significantly change these recommendations. New water storage facilities to provide the recommended amounts on a more regular basis than at present are not needed to maintain the existing fishery characteristics and would likely lead to significant changes to the existing habitat and fish community, some of which might not be desirable.

Based on HabiTech (2004) hydrology, the instream flow recommendations constitute a small portion of annual water yield in the Marquette Creek basin, even in very dry years (Figure 9). Surplus water yield occurs during the spring runoff period, May through July (Figure 9). For the remainder of the year, the 1.1 cfs recommendation is higher than flows estimated to occur in dry, average and wet years. Rather than recommend a lower flow, 1.1 cfs is recommended so that the fishery will have the opportunity to benefit on the occasions that flow is naturally available.
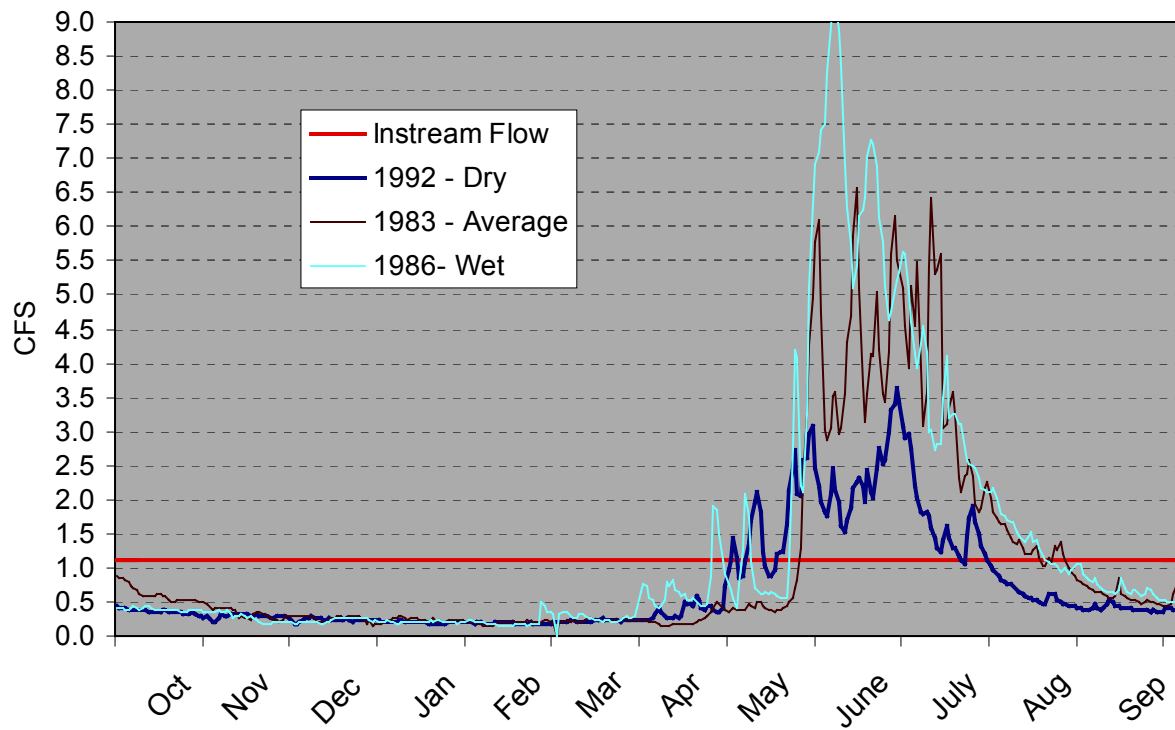
Figure 9. Marquette Creek instream flow recommendations and hydrographs from representative water years in three exceedance classes: wet (0-10%), average (30-70%), and dry (90-100%).

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APPENDIX 1. CHANNEL MAINTENANCE FLOWS

The term "channel maintenance flows" refers to flows that maintain existing channel morphology, riparian vegetation and floodplain function (US Forest Service 1997, Schmidt and Potyondy 2004). The basis and approach used below for defining channel maintenance flows applies only to snowmelt-dominated gravel and cobble-bed (alluvial) streams. By definition, these are streams whose beds are dominated by loose material with median sizes larger than 2 mm and with a pavement or armor layer of coarser materials overlaying the channel bed. In these streams, bedload transport processes determine the size and shape of the channel and the character of habitat for aquatic organisms (Andrews 1984, Hill et al. 1991, Leopold 1994).

A flow regime that provides channel maintenance results in stream channels that are in approximate sediment equilibrium where sediment export equals sediment import on average over a period of years (Leopold 1994, Carling 1995, Schmidt and Potyondy 2004). Thus, stream channel characteristics over space and time are a function of sediment input and flow (US Forest Service 1997). When sediment-moving flows are removed or reduced over a period of years, some gravel-bed channels respond by reducing their width and depth, rate of lateral migration, stream-bed elevation, bed material composition, stream side vegetation and water-carrying capacity.

Maintenance of channel features and floodplain function cannot be obtained by a single threshold flow (Annear et al. 2004). Rather, a dynamic hydrograph within and between years is needed (Gordon 1995; Trush and McBain 2000, Schmidt and Potyondy 2004). High flows are needed in some years to scour the stream channel, prevent encroachment of stream banks and deposit sediments to maintain a dynamic alternate bar morphology and successionally diverse riparian community. Low flow years are as valuable as high flow years on some streams to allow establishment of riparian seedlings on bars deposited in immediately preceding wet years (Trush and McBain 2000). The natural interaction of high and low flow years maintains riparian development and aquatic habitat by preventing annual scour that might occur from continuous high flow (allowing some riparian development) while at the same time preventing encroachment by riparian vegetation that could occur if flows were artificially reduced at all times.

Channel maintenance flows must be sufficient to move the entire volume and all sizes of material supplied to the channel from the watershed over a long-term period (Carling 1995, Schmidt and Potyondy 2004). A range of flows, under the dynamic hydrograph paradigm, provides this function. Infrequent high flows move large bed elements while the majority of the total volume of material is moved by more frequent but lower flows (Wolman and Miller 1960, Leopold 1994). In streams with a wide range of sediment sizes on the channel boundary, a range of flows may best represent the dominant discharge because different flow velocities are needed to mobilize different sizes of bed load and sediment. Kuhnle et al. (1999) note "A system designed with one steady flow to transport the supplied mass of sediment would in all likelihood become unstable as the channel aggraded and could no longer convey the sediment and water supplied to it. A system designed with one steady flow to transport the supplied sediment size distribution would in all likelihood become unstable as the bed degraded and caused instability of the banks."

A total bedload transport curve (Figure 1-1) shows the amount of bedload sediment moved by stream discharge over the long-term as a product of flow frequency and bedload transport rate. This schematic shows that any artificial limit on peak flow prevents movement of the entire bedload through a stream over time and would result in gradual bedload accumulation. The net effect would be an alteration of existing channel forming processes and habitat (Bohn and King 2001). For this reason, the 25-year peak flow is the minimum needed to maintain existing channel form.
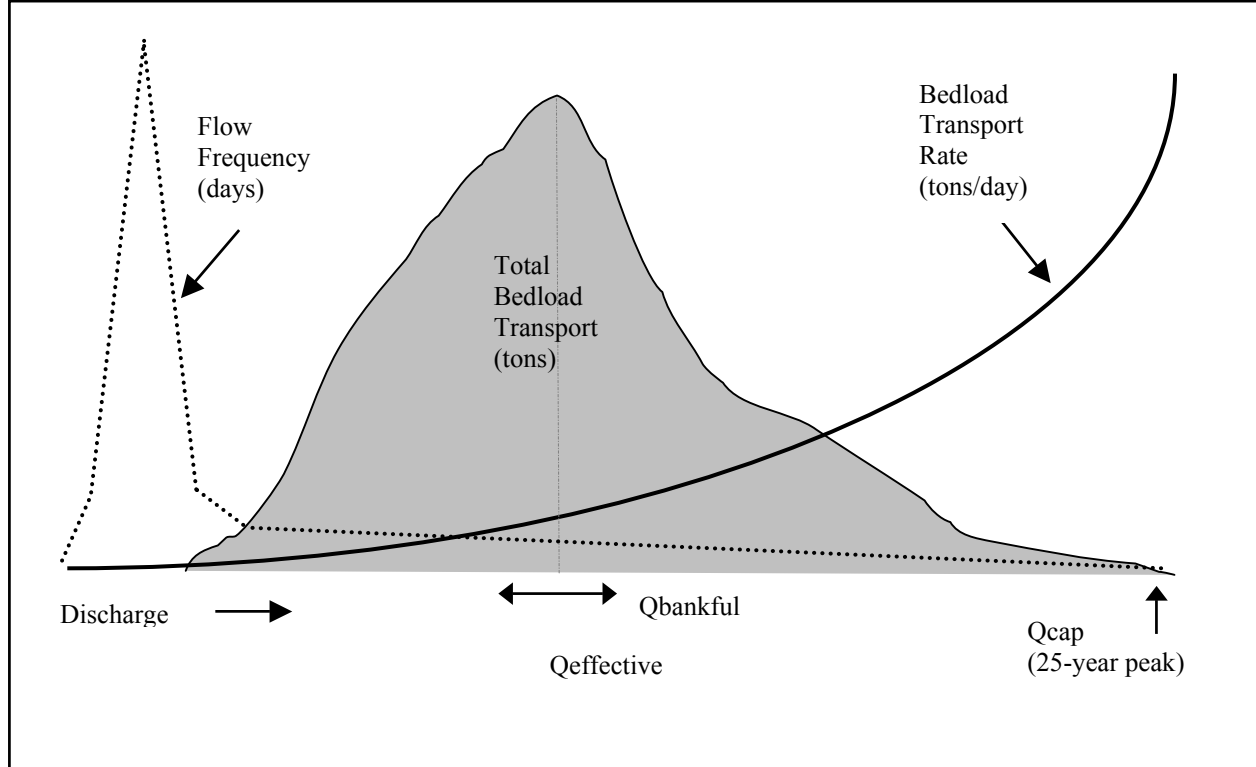
Figure 1-1. Total bedload transport as a function of bedload transport rate and flow
   frequency (adapted from Schmidt and Potyondy 2004).

The initiation of particle transport begins at flows somewhat greater than average
annual flows but lower than bankfull flows (Schmidt and Potyondy 2004). Ryan (1996) and
Emmett (1975) found the flows that generally initiated transport were between 0.3 and 0.5 of
bankfull flow.   Movement of coarser particles begins at flows of about 0.5 to 0.8 of bankfull
(Carling 1995, Leopold 1994). Schmidt and Potyondy (2004) discuss phases of bedload
movement and suggest that a flow trigger of 80% of the 1.5-year discharge "provides a good
first approximation for general application" in defining flows needed to maintain channels.
They suggest that although lower flows will initiate fine sediment movement, "delaying the
initiation point of the channel maintenance hydrograph (to $0.8 * Q_{bf}$), is desirable because it
minimizes the long-term volume of water needed for channel maintenance."

Based on these principles, the following model was developed by Dr. Luna Leopold and
is used in this report:

$$Q \text{ Recommendation} = Q_f + \{(Q_s - Q_f) * [(Q_s - Q_m) / (Q_b - Q_m)]^{0.1}\}$$

Where: Q_s = actual stream flow
Q_f = fish flow
Q_m = substrate mobilization flow = $0.8 * Q_b$
Q_b = bankfull flow

The model is identical to the one presented in Gordon (1995) and U.S. Forest Service
(1994) with one variation. The model presented in those documents used the average annual flow
as the flow at which substrate movement begins. This term was re-defined here as the substrate
mobilization flow (Q_m) and assigned a value of 0.8 times bankfull flow based on the report by
Schmidt and Potyondy (2004). Setting Q_m at a higher flow level leaves more water available for
other uses and thus better meets the statutory standard of "minimum needed".

Application of the equation results in incrementally higher percentages of flow
applied toward channel maintenance as flow approaches bankfull (Figure 1-2). Flows less
than half of bankfull are available for other uses unless needed for direct fish habitat.   At
flows greater than bankfull but less than the 25-year flow level, the channel maintenance

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instream flow recommendation is equal to the actual flow. Flows greater that the 25-year recurrence flow are not necessary for channel maintenance and are available for other uses.

Under the dynamic hydrograph approach, the volume of water required for channel maintenance is variable from year to year. During low flow years, less water is required for channel maintenance because flows may not reach the defined channel maintenance level. In those years, most water in excess of base fish flows is available for other uses. The majority of flow for channel maintenance occurs during wet years. One benefit of a dynamic hydrograph quantification approach is that the recommended flow is needed only when it is available in the channel and does not assert a claim for water that is not there as often happens with threshold approaches.
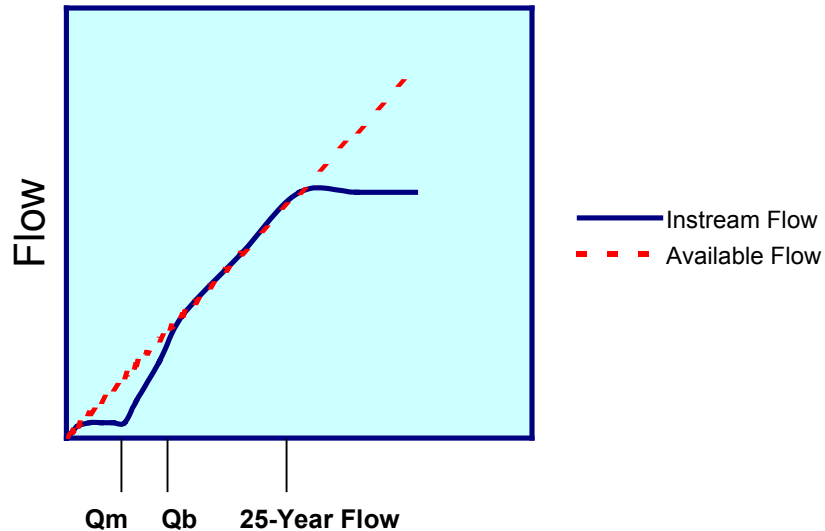

Figure 1-2. General function of a dynamic hydrograph instream flow for fishery maintenance. Q_m is substrate mobilization flow and Q_b is bankfull flow.

The Leopold equation yields a continuous range of instream flow recommendations at flows between the sediment mobilization flow and bankfull for each cubic foot per second increase in flow (Figure 1-2). This manner of flow regulation is complex and could prove burdensome to water managers. To facilitate flow administration while still ensuring reasonable flows for channel maintenance, we modified this aspect of the approach to claim instream flows for 4 evenly partitioned blocks or increments of flow between the sediment mobilization flow and bankfull (see Table 1-1).

Like all properly functioning rivers, the Marquette Creek instream flow segment has a hydraulically connected watershed, floodplain, riparian zone and stream channel. Bankfull and overbank flow are essential hydrologic characteristics for maintaining the habitat in and along these river segments in their existing dynamic form. These high flows flush sediments from the gravels on an annual or more often basis and maintain channel form (depth, width, pool and riffle configuration) by periodically scouring encroaching vegetation. Overbank flow maintains recruitment of riparian vegetation, encourages lateral movement of the channel, and recharges ground water tables. Instream flows that maintain the connectivity of these processes over time and space are needed to maintain the existing fishery (Annear et al. 2004).

Applying the Leopold equation and approach yielded the channel maintenance instream flow recommendations in Table 1-1. The base or fish flow used in the analysis was the 1.1 cfs Habitat Retention flow. For naturally available flow levels less than the Habitat Retention flow, the channel maintenance instream flow recommendation is equal to natural flow. The Habitat

retention flow level is considerably less than the substrate mobilization flow (6.4 cfs). For the flow range between the Habitat Retention flow and the substrate mobilization flow, the channel maintenance flow recommendation is equal to the Habitat Retention flow (Table 1-1). When naturally available flows range from the substrate mobilization flow to the bankfull flow level, application of the Leopold formula results in incrementally greater amounts of water applied toward instream flow (Table 1-1). At flows between bankfull and the 25-year flood flow (18 cfs), all of the streamflow is needed to perform channel maintenance functions. At flow greater than the 25-year flood flow, only the 25-year flood flow is needed for channel maintenance because this flow level will have moved the necessary amount of bed load materials and reconnected the channel with the floodplain (Figure 1-2).

Table 1-1. Channel maintenance instream flow recommendations (shaded columns) to maintain existing channel forming processes and long-term aquatic habitat characteristics in the Marquette Creek instream flow segment. Recommendations apply to the run-off period from April 1 through July 30.

Flow Level Description	Flow (cfs)	
	Available	Channel
<Habitat Retention flow*	<1.1	<1.1
Habitat Retention flow	1.1	1.1
<Substrate Mobilization	1.1 – 6.4	1.1
Substrate Mobilization	6.4	1.1
Mobilization to Bankfull	6.5 – 6.8	5.2
Mobilization to Bankfull	6.9 – 7.2	6.3
Mobilization to Bankfull	7.3 – 7.6	7.0
Mobilization to Bankfull	7.7 – 7.9	7.6
Bankfull	8.0	8.0
Bankfull to 25-Year Flood[#]	8.1 – 17	8.1 - 17
25-Year Flood	18	18
> 25-Year Flood	>18	18

*At stream flows less than the Habitat Retention flow, the flow recommendation is all available flow.
Between bankfull and the 25-year flow, the flow recommendation is all available flow.

Figure 1-3 shows examples of channel maintenance flow recommendations implemented in a randomly selected average, moderately wet and wet year. Dry or moderately dry years are not shown because during most of these years flows would not exceed the 6.4 cfs substrate mobilization threshold to initiate channel maintenance flows. In the representative average year, 1983, flow exceeded 6.4 cfs on a single day (6.6 cfs) yielding a flow recommendation of 5.4 cfs for that day (Table 1-1). In moderately wet 1999, flow exceeded 6.4 cfs for nine days in June. Flow exceeded the 8.0 cfs bankfull level on four of the nine days, resulting in flow recommendations equal to available flow (Table 1-1). In wet 1986, channel maintenance flow recommendations would be in play for 15 days in May and June (Figure 1-3).

If water storage were developed (though it is not recommended for this cutthroat trout fishery) it would be necessary to further specify the rate at which releases could be increased or decreased to the channel maintenance levels. The sharp flow increases and decreases evident in Figure 1-3 could cause habitat loss through excessive scour and potential trout mortality due to stranding. More gradual changes akin to a natural hydrograph would be recommended. In that case, the Index of Hydrologic Alteration (IHA; Richter et al. 1996) could provide a valuable reference. Daily increases and decreases during runoff measured at the South Fork Shoshone gage could serve as guide for developing such ramping rate recommendations using the IHA.
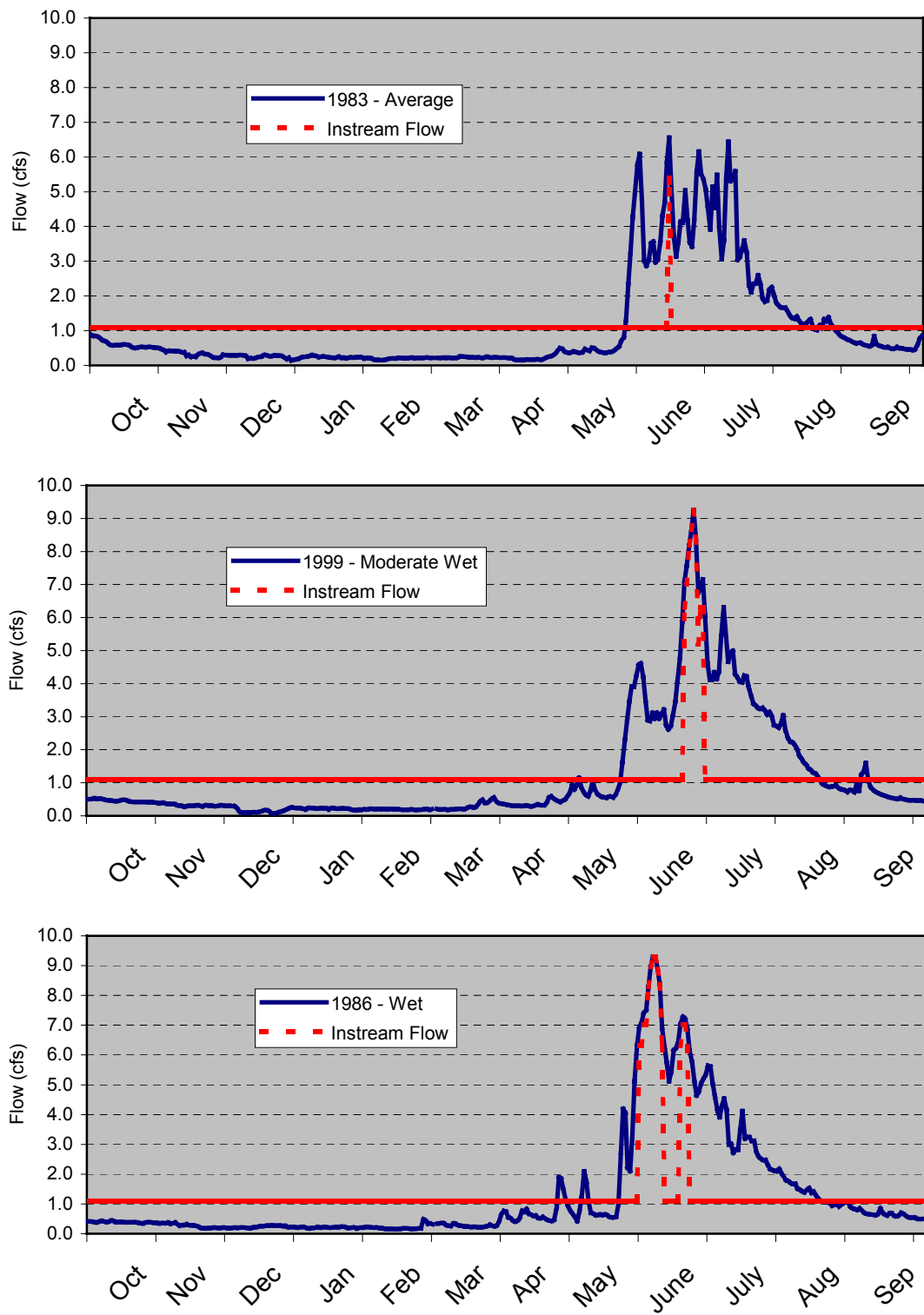
Figure 1-3. Marquette Creek channel maintenance flow recommendations and hydrographs in an average (1983), moderately wet (1999) and wet (1986) water year.
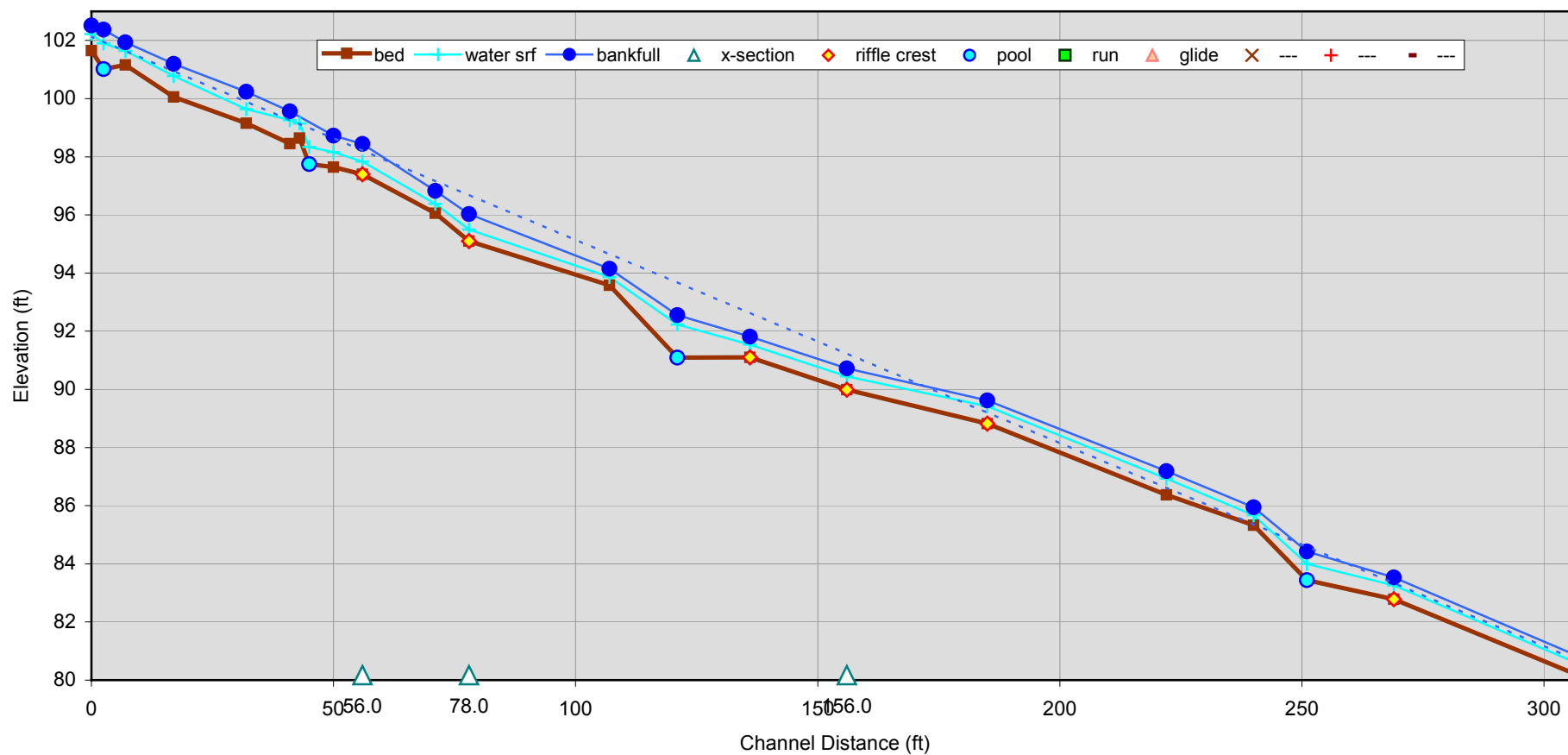
APPENDIX 2. ROSGEN LEVEL II MEASUREMENTS

Figure 2-1. Longitudinal profile through instream flow study site and HQI reach. Triangle markers indicate where Habitat Retention riffle transects were located.
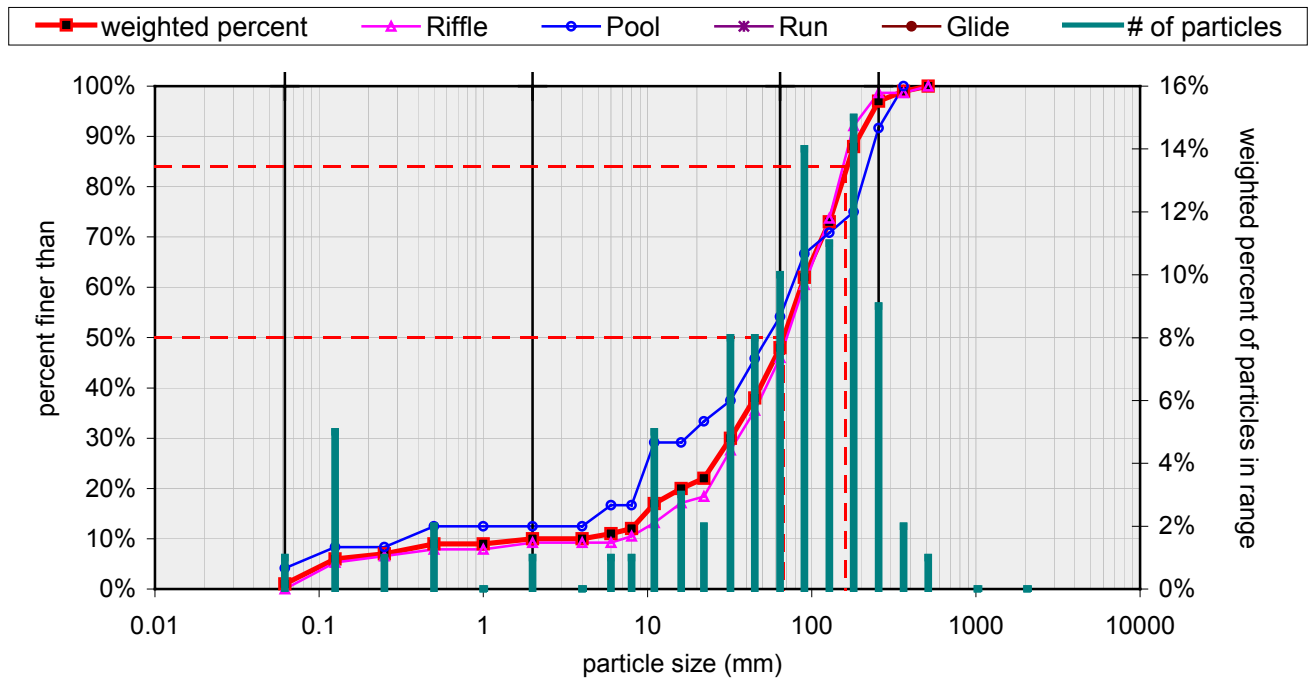
76% riffle   24% pool

Figure 2-2. Pebble count particle distribution.